Draft May 2008

Irrigation Water Pricing Policy in Rural China

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Revised version of Selected Paper presented at American Agricultural Economics Association Annual Meeting, July 23-26, 2006, Long Beach, CA

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Abstract

The goal of this paper is to analyze the potential of reforming water pricing as a way to encourage water conservation and to assess its impacts on crop production and producer welfare in rural China. To meet this goal, we develop an approach that can inform policy makers about the effectiveness of water pricing policy as well as how water pricing policy should be implemented. The first step in the approach involves estimating a set of crop-specific production frontiers as well as household level technical inefficiency parameters. The estimation results aid us in measuring the relationship between water and crop output as well as the value of water to households. Our results indicate that there is a large gap between the value of water and the current water cost in many places. Simulation analyses show that reforming water pricing can induce water savings but the price of water needs to be raised to a relatively high level. We also find that a water pricing policy that takes into account this gap (the *informed* policy) can be more effective than a policy that ignores it (the *uninformed* policy) in that it generates larger water savings given the same increase in the average price of water. Raising the price of water negatively affect crop production and crop income, which means supplementary polices should be used to compensate farmers. Higher water prices do not adversely affect the distribution of household income.

Irrigation Water Pricing Policy in Rural China

Water scarcity is one of the key problems affecting northern China. Water availability per capita in North China is only around 300 m^3 per capita, less than one seventh the national average and far below the world average (Ministry of Water Resources, 2002). Past water projects have tapped almost all of the region's surface water resources. At the same time, the rapidly growing industrial sector and an increasingly wealthy urban population begin to compete with the agricultural sector for water. As a result, surface water supplies are becoming increasingly stressed and groundwater resources are diminishing in large areas of northern China. For example, between 1958 and 1998 groundwater levels in the Hai River Basin (HRB) fell by up to 50 meters in some shallow aquifers and by more than 95 meters in some deep aquifers (Ministry of Water Resource, World Bank and AusAID, 2001).

Most of China's past water policies have focused on the supply side to tackle water scarcity problems. Priorities were given to increasing water supply through constructing more canals and larger reservoirs (Ross, 1983). Between 1980 and 1997 China invested more than 171 billion yuan into water control (measured in 1990 yuan — Fan, Zhang and Zhang, 2002).[1] In 2001 the State Council began the construction of the South-to-North Water Transfer Project, a project that will cost billions of dollars.

It is becoming increasingly clear, however, that a supply-side only approach is not sufficient to deal with the growing water scarcity. Gradually China's leaders have started to recognize the need to stem the rising demand for water from all sectors (Boxer, 2001). For example, since the early 1990s, leaders have encouraged households to adopt water saving technologies (Lohmar, et al., 2003). Unfortunately, most of their efforts to encourage the use of

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[1] Yuan is the unit of currency used in China—one dollar equals about 8 yuan in 2004 and drops to about 7 yuan in 2008.

modern water-saving technologies, such as drip irrigation and sprinkler irrigation, have failed. In more recent years water officials also promoted water management reforms by providing canal managers with better incentives to save water (Wang, et al., 2005). However, these reforms have not been effectively implemented across wide regions across China .

Under these circumstances, China's water officials and scholars have begun to consider reforming the pricing of irrigation water as an important policy instrument for dealing with the water scarcity problem (e.g., Wang, 1997; Wei, 2001). When trying to explain the low adoption rates of water saving technologies and the limited success of water management reforms, researchers invariably have speculated that one of the reasons for the failure was the absence of economic incentives facing water users (Lohmar, et al., 2003; Yang, Zhang and Zehnder, 2003). Similar to the situation in many places around the world, the cost of water is low in China. Groundwater users only need to pay for the cost of energy to pump water out. No extraction fees are charged. Surface water also was priced much lower than its engineer cost (Zheng, 2002). Despite the fact that agricultural sector is the main water-using sector in China (68% in 2001, Ministry of Water Resources, 2002), charges for irrigation water have not been raised much. Furthermore, inside most irrigation districts, water fees are assessed based on the size of irrigated area. When the cost of water is low or not related to the quantities demanded, the benefit from saving water also is low. As a result, the current water pricing policy in the agricultural sector (as oppose to the industrial and residential sectors) has not been effective in providing water users with incentives to save water.[2] Reform is needed to make the price of water reflect the true value of water so that agricultural users will have any incentive to save water.

While there is increasing consensus that reforming water pricing is necessary, two basic

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[2] China's government has raised the price of water that is charged for residential use and industrial use. For example, the price of tap water in Beijing has been raised 9 times since 1991, from a level of 0.12 Yuan/m^3 to 3.7 Yuan/m^3 (Chen, 2005).

issues need to be addressed before any new policies can be made. The first issue is the effectiveness of increasing the cost of irrigation. Previous economic studies in a number of developed countries have shown that demand for irrigation water inelastic (e.g., Moore, Gollehon and Carey, 1994; Ogg and Gollehon, 1989). If water users in China are not responsive either, raising the price of water will not be an effective mechanism to reduce demand. If water users do respond to price changes, it is important for policy makers to learn about the nature of the responses when planning price interventions. This is because water use reduction could reduce crop production and thus affect China's food security.

The second issue is the welfare impact of higher irrigation costs on producers. In the political-economy environment that dominates policy making in China today, it is absolutely imperative to assess how much producers would be hurt should pricing policies be effectively implemented. The current government is intent on reducing farmer burdens and raising incomes even if other long term problems (e.g., the unsustainable tapping of groundwater resources) are undermined (Lohmar, et al., 2003).

Despite the fact that dealing with water scarcity is among the most critical issues on the government agenda and that good policies require that officials understand the nature of water demand, only few studies have analyzed water demand in rural China (e.g., Chen, et al., 2005; Yang, et al., 2003). Many of previous studies are largely qualitative. To our knowledge there are rarely any rigorous quantitative analyses of household water demand that can be used to advise China's policy makers.

The goal of this paper is to analyze the potential of reforming groundwater pricing as a way to encourage water conservation and to assess its impacts on crop production and producer welfare in rural China. To meet this goal, we develop an approach that can inform policy makers about the effectiveness of water pricing policy as well as how water pricing policy should be implemented. The first step in the approach involves estimating a set of crop-specific production frontiers as well as household level technical inefficiency parameters. The estimation results aid us in measuring the relationship between water and crop output as well as the value of water to households. Our results show that in general there is a large gap between the cost of water and the value of water to producers. Using the estimation results in a series of simulation analyses, we examine the effects of water pricing policy on water savings. In particular, we examine two different water pricing policies, one that takes into account the gap between the cost of water and the water value (henceforth, the *informed policy*); the other ignores this gap (henceforth, the *uninformed* policy). Finally, we analyze the impacts of water pricing policy on crop production, especially that of grain crops and producer welfare.

The rest of the paper is organized as follows. In the first section we describe the data set that forms the basis of the study. In the second section we describe the relationship between water cost and water use that we observe in the data. In the third section we introduce the household water demand framework and the estimation approach. The results of the estimation are reported and used in the next section to simulate the effects of raising water prices on household water use, crop production and household income. The final section concludes.

Data Description

The data used in the study come from the 2004 China Water Institutions and Management (CWIM) Survey, which was jointly run by the authors. We collected household level data in 24 communities in Hebei province, a province that covers most of the HRB and surrounds Beijing. About 12% of China's grain is produced in Hebei province (Ministry of Agriculture of China, 2004). The communities were chosen randomly from three counties randomly selected according to their locations, which were correlated with the extent of water scarcity in the HRB. Xian County is located along the coastal belt (the most water scarce area of China); Tang County is located along the inland belt (an area with relatively abundant water resources since it is next to the mountains in the eastern part of Hebei province); and Ci County is located in the region between the coast and mountains.

In the survey we collected data on household level production activities, in particular, irrigation water use, during year 2004. The major crops in Hebei province are wheat, maize and cotton. Wheat is planted in the previous winter and harvested in spring. Maize and cotton are planted in summer and harvested in the fall. For each crop, we collected information on yields, crop prices, costs and quantities of each type of input: fertilizer, labor (by production activity), machinery (use of own equipment or rent), pesticide, plastic sheeting, etc. To construct a measure of the volume of water applied, we asked households to report for each crop the length of irrigating time, the total number of irrigations during the entire growing season and the volume of water applied per irrigation. In addition, we also asked households to report the amount they paid for irrigation water for each crop in order to calculate the cost of water. The average cost per m^3 of water is treated as the price of water. In the rest of paper, the cost of water and the price of water are used interchangeably.

Nature of irrigation water demand in northern China

The characteristics of our sample data allow us to study the nature of irrigation water demand in northern China. Most importantly, we observe large variations in the prices of water paid by households in our data. All communities in our sample data rely on groundwater as the major source of irrigation water. Most variations in water prices come from the differences in the depth to water in wells across space. This can be seen by the strong positive correlations between the price of water and the depth to water for wheat, maize and cotton (Table 1, column 1 and 2). Households that paid more for per unit of water are usually those that faced greater depth to water because it cost more to pump water out. Moreover, since the depth to water varies significantly across space, from less than 20 meters to more than 100 meters (column 1), households in different quartiles of depth to water paid very different prices for water. For example, maize-growing households in the fourth quartile (the farmers pumping from the deepest wells) paid as much as 0.51 yuan/m^3 for water while those households in the first quartile paid as little as 0.05 yuan/m^3 (column 2, row 7 and 10).

With the large variations in the prices of water across space, we observe several differences in water using patterns. First, we observe a strong inverse relationship between the price of water and the level of water use among households that irrigated their crops. As the price of water rises, households adjust water use by cutting down their water use per unit of irrigated area. In this paper, we define this as *adjustments at the intensive margin* or stress irrigation. For example, wheat-growing households that face a price of 0.07 yuan/m^3 water applied 5,321 m^3/hectare; other wheat-producing households that pay 0.5 yuan/m^3 used only 2,276 m^3/hectare (Table 1, column 2 and 3, row 2 and 5). There also are large adjustments and monotonically decreasing water use among households that grew maize or cotton in response to rising water prices.[3]

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[3] It should also be noted that, on average, crop water use calculated from the survey data is consistent with findings from agronomy studies in China. The estimated crop irrigation water requirement (the difference between evapotranspiration and effective precipitation) in Hebei province, conditional on the average rainfall level between 1952 and 1998, was shown to be 2,620 m^3/hectare for wheat, 1,340 for maize and 1,260 for cotton (Chen, et al., 1995). Taking into account irrigation system efficiencies (which have been estimated to be between 0.6 and 0.7 in Hebei province, Chen, et al., 1995), the levels of crop water use from our data (in the column 3 of Table 1) are close

In addition to the adjustments at intensive margin, households also respond to price increases in several other ways. In particular, households may choose not to irrigate some of their crops or change their crop mix. We defined these responses as *adjustments at the extensive margin*. On average households in the first quartile of depth to water left 12% of their sown area to be rainfed (Table 2, row 1, column 2). The share of sown area that is rainfed increases to 37% among households in the fourth quartile of depth to water (row 4, column 2).

Households also tend to allocate greater shares of sown area to non-grain crops as the depth to water increases. In our data, non-grain crops include cotton, vegetables, fruits, flowers and peanuts. On average, the households in the first quartile allocate 15% of their sown area to non-grain crops (Table 2, row 1, column 3). The share is more than doubled for households in the third and fourth quartiles (rows 3 and 4, column 3). Such patterns are consistent with findings of other studies in the US (e.g., Gardener, 1983). Relative to grain crops such as wheat and maize, non-grain crops usually generate higher per-hectare net return but also impose higher non-water costs since they are more labor- and capital-intensive. Changes in relative prices caused by increases in water prices result in more uses of labor and capital. This could bring on a crop mix change away from grain crops toward non-grain crops.

Household water demand framework and estimation approach

Our data show that households respond to changes in water prices through intensive margins as well as through extensive margins. Given this nature of water demand, it is more meaningful to analyze water use at the household level instead of the crop level. The latter cannot capture the extensive margin adjustment. In this section, we first introduce the household maximization

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to these estimates. Because the growing season of maize and cotton (late July or August to October) coincides with the rainy season in Hebei province, they require much less irrigation water than wheat.

model from which household water demand is derived. We then lay out the methods we use to estimate the production frontier and technical inefficiency parameters, the key elements in measuring relationship between water and output.

Household water demand framework

Most of our sample households are engaged in producing multiple crops including wheat and maize (Table 3, row 1). Some households also grow cotton. Five inputs are used in production. Two inputs are variable inputs: capital (x_k) and fertilizer (x_f). Capital costs, which could also be called material costs, include expenditures on machinery, seed, plastic sheeting, herbicides and pesticides. It is assumed the farmers can purchase fertilizer at unlimited quantities at the market price. Land (x_L), family labor (x_{fl}) and water (x_w) are treated as fixed allocatable inputs.[4]

Households are assumed to maximize the total profit from all three crops. The profit maximization assumption is supported by many previous studies on production behavior in China (e.g., Huang and Rozelle, 1996; Lin, 1992). The constrained profit maximization problem (*problem P1*) can be expressed as:[5]

$$\underset{x_{ij}}{\text{Max}}\ \sum_j p_j \theta f_j(x_{Lj}, \gamma x_{wj}, x_{lj}, x_{fj}, x_{kj}) - \sum_i c_i x_{ij}$$

$$\text{Subject to:} \quad \sum_j x_{ij} \le B_i \ \ \forall i = \text{ Land, Labor, Water}$$

$$x_{ij} \ge 0$$

where the output price for crop *j* is p_j and the production frontier for crop *j* is f_j. The parameter, θ, is the technical inefficiency parameter. The cost for input *i* is c_i. B_i represents the vector of

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[4] In rural China, the collective (or community) allocates land to each household based largely upon the size of the household. There is no cost for land except for plots that are rented. Only a small proportion of plots are rented (about 3% in 1995 and 7% in 2000—Brandt, Rozelle and Turner, 2004). Hence we assume there is no cost for land, but that it is fixed. In addition to family labor, which is fixed by definition, labor input also may include hired labor (x_{hl}). Since in our data and in all of China, only a small percentage of farm labor is hired (Benjamin and Brandt, 2002), we believe that we can assume that labor is largely a fixed input. While there are no formal restrictions on pumping in the sample communities (Wang, Huang and Rozelle, 2005), our data show that in some communities the quantity of groundwater may be constrained (at least short run—that is during the irrigation season).

[5] In our preliminary analysis, we assumed households were risk averse. The risk aversion parameter, however, did not come out statistically different from zero in estimation. Therefore, without loss of generality, we assume households are risk neutral.

available quantities of the *i*th fixed allocatable input. Although households pay for all the irrigation water they apply to their crops, only a proportion of that water is consumed by crop due to conveyance loss or return flow to the aquifer. The symbol, γ, denotes the proportion of the applied water that crops consume and thus contributes to crop growth.[6] The parameter γ is suppressed in the rest of the paper for the sake of brevity.

Let W denotes household level total water use. The total effect of a change in water price on W can be shown to be:

$$\frac{dW}{dc_w} = \sum_{j=1}^{J}\left(\frac{\partial x_{wj}}{\partial c_w} + \frac{\partial x_{wj}}{\partial L_j}\frac{\partial L_j}{\partial c_w}\right) \tag{1}$$

The first term, $\frac{\partial x_{wj}}{\partial c_w}$, represents the change in crop-level water use when the land allocation is held constant, that is, the intensive margin adjustment. Comparative statics show that $\frac{\partial x_{wj}}{\partial c_w} < 0$.

The second term, $\frac{\partial x_{wj}}{\partial L_j}\frac{\partial L_j}{\partial c_w}$, represents the change in crop-level water use operated through land reallocation, that is, switching between irrigated area and rainfed area within the same crop, or changes in cultivated area across different crops. This is the extensive margin adjustment. Depending on the specific crop, $\frac{\partial x_{wj}}{\partial L_j}\frac{\partial L_j}{\partial c_w}$ may be positive or negative. Summing over the intensive and extensive margins of all J crops, we get the household level response to changes in water prices. From equation (1), it is clear that to characterize the household level water demand, we need to consider both the intensive and extensive margin adjustments. To do so, we need to

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[6] Kim and Schaible (2000) and Scheierling et al. (2004) have shown that if the amount of irrigation water applied, instead of the amount of water actually consumed by the crop, is considered as the amount of water that contributes to crop growth in crop production, the marginal benefit of water will be overestimated.

estimate two sets of parameters: the production frontier, f_j, and the technical inefficiency parameter, θ.

Production frontier and Generalized Maximum Entropy

We estimate one set of crop specific production function for each county, allowing production technology to vary by county, but restricting it to be equal across communities within the same county.[7] Since the price responsiveness of water demand depends on its own- and cross-price elasticities, a flexible functional form should be used so that these relationships are not arbitrarily restricted by the choice of the functional form. We specify a quadratic function frontier:

$$Y_{jn} = \theta_n \left(\sum_i \alpha_{ij} x_{ijn} - \sum_i \sum_{i'} x_{ijn} z_{ii'j} x_{i'jn} \right) + e_{jn} \tag{2}$$

The observed output and input use of household n for crop j are denoted by Y_{jn} and x_{ijn}, respectively. The symbol, θ_n, denotes the technical inefficiency of household n. The error term, e_{jn}, captures variation in outputs due to random events such as weather.

Estimating a flexible production frontier, however, would make the use of some estimation methods difficult or even infeasible. Since five inputs are used in production and a quadratic functional form is specified, there are 20 parameters to be estimated for each production frontier. If classical econometric methods (e.g., maximum likelihood estimation) were used, the estimation problem would be ill-posed due to insufficient number of data points. For example, when we estimate a production frontier for wheat in Tang and Ci County, there are only 18 and 19 data points respectively (Table 3, row 3 and 4, column 2). This means that there

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[7] Since we have a set of household level data, in addition to producing one set of estimates for each county, we also have the choice of estimating one set of production function parameters for each community to capture more heterogeneity across space but doing so with fewer observations per set of estimates. We also could estimate at the province level, which while ignoring most of the heterogeneity across space, uses more observations in estimation. The choice of estimating production function at the county level was made after comparing the ability of all three sets of models (the province-level model, the county-level model and the community-level model) to capture heterogeneity across space and their predictive accuracy. The approach to choose among different models for the purpose of policy analysis is developed in Huang, Rozelle and Howitt (2008).

are fewer observations than the number of parameters.

As a solution, we choose to use the Generalized Maximum Entropy (GME) method that was developed by Golan, et al. (1996). The GME estimator allows for estimation with any sample size. The GME estimator emphasizes both prediction and precision in its objective function and thus has the properties of being both subject to limited bias and minimum variance (Golan, et al., 1996). Under very general conditions, the GME estimator also has desirable large sample properties, including both asymptotic efficiency and asymptotical normality. It should be noted that if the number of data points were sufficient, classical econometric methods and GME would produce the same estimation results.

In GME estimation, in addition to the *data-consistent constraints*, which are specified in equation (2), two additional sets of constraints are specified that will aid us in: a.) making our estimates consistent with economic theory (the *theoretical constraints*); and c.) implementing the GME estimation (the *numeric estimation constraints*).

Theoretical Constraints

Two sets of theoretical constraints are used so that the estimated production technology is consistent with the profit maximization behavior of households. The first set is the *optimality condition constraints*:

$$x_{ijn} = \frac{1}{2z_{ii}}\left[\alpha_{ij} - 2\textstyle\sum_{i' \neq i} x_{i'n} z_{ii'} - \frac{c_{in}}{p_j \theta_n}\right] + v_{ijn} \quad \forall i = \text{Fertilizer, Capital} \qquad (3)$$

We only include the optimality conditions for variable inputs. The optimality conditions for fixed allocatable inputs include the shadow values, which are not directly estimatable.

The second set of theoretical constraints is the *curvature constraint*, which requires that **Z**, the matrix of all parameters on the squared and interaction terms of inputs ($z_{ii'j}$ s), be positive (semi)definite. The curvature constraint is imposed using the Cholesky decomposition (Paris and Howitt, 1998). The Cholesky decomposition is defined by **Z** = LL', where L is an $I \times I$ lower triangular matrix, I is the total number inputs. The positive (semi)definite property of **Z** is guaranteed by constraining the diagonal elements of L to be nonnegative ($L_{iij} \geq 0$). The Cholesky decomposition also ensures the symmetry of the matrix **Z**. In addition, we also impose the monotonicity constraints: $p_j \theta_n \left[\alpha_{ij} - 2\sum_{i'} x_{i'n} z_{ii'} \right] - c_{in} > 0$.[8]

Numeric estimation constraints

When the GME method is used, instead of directly estimating the mean and variance of the coefficient, a probability distribution is estimated for each coefficient and the error term. Several possible values of a coefficient are chosen as the *support values* of the probability distribution and an unknown probability is assigned to each value.[9] The coefficients and the error terms are then reparameterized in terms of unknown probabilities and support values. This set of *reparameterization constraints* are defined as $\alpha_{ij} = \sum_m p^m_{\alpha_{ij}} \bar{\alpha}^m_{ij}$, $z_{ii'j} = \sum_m p^m_{z_{ii'j}} \bar{z}^m_{ii'j}$, $v_{ijn} = \sum_m p^m_{v_{ijn}} \bar{v}^m_{ijn}$ and $e_{jn} = \sum_m p^m_{e_{jn}} \bar{e}^m_{jn}$, where m is the index of the support values and the ps are the unknown probabilities to be estimated. Symbols with upper bars denote the support values. The unknown probabilities positive and all probabilities associated with the same coefficient or error term add up to one (the *adding up constraints*).

Technical efficiency parameters

The parameter, θ_n, is the technical inefficiency parameter that captures the degree of deviation of each household's actual production from the production frontier. More importantly, since technical inefficiency is often the result of a lack of managerial ability (Farrell, 1957;

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[8] In our empirical estimation, the monotonicity constraints hold for all observations.

[9] We follow Golan, Judge and Miller (1996) and choose five support points for both coefficients and error terms.

Leibenstein, 1966), θ_n reflects the inter-household differences in managerial ability. Accounting for technical inefficiency is important since it can help us overcome a common problem associated with estimating a production function — the potential bias due to the existence of omitted variables. In particular, household managerial ability is often omitted because it is not directly observable to econometricians. Since the managerial ability affects both output level and the producer's choice of input, omitting it will bias the estimates of production function parameters (Griliches, 1957).[10] Since the estimated technical inefficiency parameters can capture unobservable heterogeneity that is relevant in our analysis (that is, managerial ability), we believe our estimates will be less affected by omitted variable bias.

We use the classic Farrell definition of the output distance function to measure θ_n. The output distance function for the nth household that produces a single output, $D_0(\mathbf{x}_n, y_n)$, is defined as: $\inf_{\theta_n}\{\theta_n > 0 : (y_n / \theta_n) \in P(\mathbf{x}_n)\}$. The parameter θ_n denotes the inverse of the factor by which the output y_n could be increased while still remaining within the feasible production set, $P(\mathbf{x}_n)$, for the given input level $\mathbf{x}_n$. The value of $D_0(\mathbf{x}_n, y_n)$ is less than or equal to one if y_n is an element of $P(\mathbf{x}_n)$. If $D_0(\mathbf{x}_n, y_n)$ is one, then the observation $(\mathbf{x}_n, y_n)$ is on the production frontier.

Data Envelopment Analysis (DEA) involves measurement of efficiency for a given observation in the sample data relative to the boundary (that is, the production frontier) of the convex hulls of the data intersected with the free-disposal hull. The distance function, $D_0(\mathbf{x}_n, y_n)$ is estimated by solving a Linear Programming (LP) problem (Charnes, Cooper and Rhodes, 1978; Färe and Primont, 1995; Farrell, 1957). The problem (*problem* P2) can be expressed as:

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[10] Conventional panel data models, such as fixed-effects or random-effects models, have been employed to account for unobserved heterogeneity. Unfortunately, for most households in our sample, we do not have more than one observation for a single crop. Therefore, it is not possible to use a household fixed effects approach.

$$\underset{\theta_n, z_1, z_2, \ldots, z_H}{\text{Max}} \ 1/\theta_n$$

$$Subject\ to: \begin{cases} \sum_{h=1}^{H} z_h y_{jh} \geq y_{jn}/\theta_n, j = 1, 2, \ldots, J \\ \sum_{h=1}^{H} z_h x_{ih} \leq x_{in}, i = 1, 2, \ldots, I \\ \sum_{h=1}^{H} z_h \leq 1 \\ z_h \geq 0,\ h = 1, \ldots, H \end{cases}$$

where the variable, z_h, represents the intensity level of the production activity of household *h*. The constraints in the LP problem specify disposability (which corresponds to the monotonicity of the production frontier) and the convexity of the feasible production set (which corresponds to the concavity of the frontier). Note these assumptions are consistent with the theoretical constraints in the GME estimation of the frontier parameters.

Summary of estimating demand parameters with GME and DEA

In GME estimation, the estimates of probabilities given their support values are obtained through maximizing the negative joint entropy of the distributions of the coefficients and the error terms conditional on the data-consistent constraints, the theoretical constraints and other constraints.[11] The objective function of Problem P2 can be easily added since it is also an optimization problem. In summary, the estimation problem (*problem P3*) can be expressed:

$$\underset{p^m_{\alpha_i}, p^m_{z_{ii'}}, p^m_{e_n}, p^m_{v_{in}}}{\text{Max}} \ H(p^m_{\alpha_i}, p^m_{z_{ii'}}, p^m_{e_n}, p^m_{v_{in}})$$

$$= -\sum_{j=1}^{J} \sum_i \sum_m p^m_{\alpha_{ij}} \ln p^m_{\alpha_{ij}} - \sum_{j=1}^{J} \sum_i \sum_{i'} \sum_s p^m_{z_{ii'j}} \ln p^m_{z_{ii'j}} - \sum_{n=1}^{N} \sum_m p^m_{e_n} \ln p^m_{e_n} - \sum_{n=1}^{N} \sum_i \sum_m p^m_{v_{in}} \ln p^m_{v_{in}}$$

$$+ \sum_{n=1}^{N} (1/\theta_n)$$

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[11] We believe that our approach of estimating the production frontier does not suffer from the fundamental identification problems raised by Marschak and Andrews (1944) for several reasons. First, a system of equations is estimated including both the production frontier equation and the optimality condition equations. Second, in a separate set of analyses, we instrumented for inputs using a set of variables (input prices, whether there is a production shock or not, distance from house to plots, etc.), the results do not differ much from the case using the raw input uses. Third, since levels of output used in estimation (after correcting for the impacts of production shocks) are close to the expected levels of outputs, we believe there is no simultaneous equation bias pointed out by Hoch (1958), which is associated with using actual output instead of expected output in estimation. Finally, the reasonable range out-of-prediction errors (not reported here) further shows that there is no serious bias in our estimates. This confirms what Golan (1996) has stated: “this formulation (of GME estimation) may lead to parameter estimates that are slightly biased but have excellent precision.”

Subject to

Data consistent constraints: $Y_{jn} = \theta_n \left(\sum_i \alpha_{ij} x_{ijn} - \sum_i \sum_k x_{ijn} z_{ikj} x_{kjn} \right) + e_{jn}$

Theoretical constraints

First order conditions: $x_{ijn} = \frac{1}{2z_{ii}} \left[\alpha_{ij} - 2\sum_{i' \neq i} x_{i'n} z_{ii'} - c_{in} \big/ p_j \theta_n \right] + v_{ijn}$

Curvature conditions: $\mathbf{Z} = LL'$; $L_{iij} \geq 0$

Monotonicity: $p_j \theta_n \left[\alpha_{ij} - 2\sum_{i'} x_{i'n} z_{ii'} \right] - c_{in} > 0$

Reparameterization: $\alpha_{ij} = \sum_m p^m_{\alpha_{ij}} \bar{\alpha}^m_{ij}$, $z_{ii'j} = \sum_m p^m_{z_{ii'j}} \bar{z}^m_{ii'j}$,
$v_{ijn} = \sum_m p^m_{v_{ijn}} \bar{v}^m_{ijn}$ and $e_{jn} = \sum_m p^m_{e_{jn}} \bar{e}^m_{jn}$

Adding up constraints: $\sum_m p^m_{\alpha_{ij}} = 1$; $\sum_m p^m_{z_{ii'j}} = 1$;
$\sum_m p^m_{e_{jn}} = 1$; $\sum_m p^m_{v_{ijn}} = 1$

Output distance function $\sum_{h=1}^{H} z_h (Y_{jh} - e_{jh}) \geq (Y_{jn} - e_{jn}) / \theta_n$; $h = 1, \ldots, H$
$\sum_{h=1}^{H} z_h (x_{ijh} - v_{ijh}) \leq (x_{ijn} - v_{ijn})$
$z_h \geq 0$; $\sum_{h=1}^{H} z_h \leq 1$

Note that the production frontiers of all crops are estimated jointly. In the set of constraints imposed on the output distance function, we subtract e_{jn} from Y_{jn} and v_{ijn} from x_{ijn}. This subtraction avoids attributing any statistical noise to deviations from the frontier, a weakness of DEA that is pointed out by many researchers. We use a bootstrapping procedure that combines algorithms developed in Simar and Wilson (2007; 2000). Details of bootstrapping are not presented here but are available from authors upon request. The bootstrapping procedure allows us to simultaneously obtain standard errors of production frontier and technical inefficiency coefficients and also generate consistent estimates of technical efficiency parameters (Kneip, Park and Simar, 1998; Simar and Wilson, 2007). Problem P3 is solved using the General Algebraic Modeling System (GAMs) software. STATA is used to generate bootstrapping samples.

Effectiveness and impacts of water pricing policies in rural China

The estimation approach presented in the previous section produced reasonable estimates of the production frontier coefficients. In Table 4, for the sake of brevity, we only report the results for wheat production frontiers. The bootstrapping results show that most estimates are statistically significant. The linear coefficients (the α_is) are all positive and statistically significant. The quadratic coefficients are also reasonable. For example, coefficients on the interaction term of capital and labor, z_{lc}, are negative and statistically significant for Xian and Tang County. Since we know from the optimality condition that the sign on the cross-price elasticity of input i and i' is the opposite of the sign on $z_{ii'}$, this indicates labor and capital are substitutes. This is consistent with findings of several studies that labor and capital are substitutes in most developing countries (e.g., Garcia-Penalosa and Turnovsky, 2005; Khandker and Binswanger, 1992).

In this section, we use simulations to analyze the effects of water pricing policy on water use, crop production and household income.[12] To do so, we first parameterize the household maximization problem P1 using estimation results. Treating the current costs of water as the baseline water prices, we first run a baseline model by solving Problem P1 for each household. We then increase the price of water to several different levels but hold prices of other inputs and output constant. We solve Problem P1 at each of these new water price levels. Simulation results form the basis of our policy analyses. By comparing the changes in household water uses, we can predict the extent of water savings that occur when water prices are raised to different levels. Since the simulations also generate the level of crop outputs and household profits, we can also predict the impact on crop production and income.

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[12] Moore et al. (1994) used rigorous econometric analyses to calculate the intensive and extensive margins. In our case, since large price changes, not marginal changes in water prices, are more relevant, simulations are more appropriate.

Since wheat, maize and cotton accounts for 80% of total sown area in our sample, we only include these three crops in the simulations. If more crops, such as non-grain crops (e.g., vegetables and fruits), were included, households would be able to adjust more at extensive margins by switching to these crops. We also keep the same rotations. In summer season, only wheat is grown while in fall season either cotton or maize (or both) is grown.

Effectiveness of water pricing policy: Informed policy and Uninformed policy

The effectiveness of water pricing policy depends crucially on the responsiveness of households. If the water price is lower than the value of water to households, households will not change water uses at all in response to small changes in water prices. Thus, a necessary task in designing a water pricing policy is to determine whether the current price of water reflects the value of water to households. This is our first step in this sub-section. We then compare the effects of two types of water policies that differ in their treatment of the value of water.

The value of water is measured by the increment in household profit due to one more unit of water available to households. This method has shown to generate better estimates of water values than other approaches, especially in the presence of fixed allocatable inputs (Young, 2005). The value of water to households is calculated in two steps. In the first step, we solve problem P1 using baseline levels of prices and resource constraints. In the second step, we relax the water constraint by one unit but hold everything else constant (e.g., prices of inputs and output, constraints on land and labor). We then calculate the change in household profit. The increment in profit is the shadow value of water, which measures the value of water to household after netting out the cost of obtaining water. We can also think of the shadow value as the gap between the cost of water and the value of water to households.

Our results show that there is a large gap between the cost of water and the value of water in most households in Xian and Ci County (Figure 1, Panel A). Since resource constraints are season specific, we have calculated the value of water to households for both the summer and fall seasons. For most households in Tang County, the cost of water they paid is the same as the value of water. In Xian County, however, the gap is almost double the irrigation cost in both seasons. In Ci County, the gap is also large in both seasons. The same finding has been observed in many other countries: water is usually under-priced (Dinar and Saleth, 2005). From our results, it is clear that at least in Xian and Ci counties, households will not change their water use much in response to small increases in water prices. This unresponsiveness is due to the fact that—although higher than the current cost of water, the new price level would still be lower than the household's actual value of the water. As a result, households would still use the same level of water before the price change in their attempts to maximize their profits.

Given the large gap between the price of water and the value of water, policy makers can design two types of water policies: an *uninformed* policy and an *informed* policy. When implementing an uninformed policy, we assume policy makers are not aware that there is a gap between the current water cost and the true value of water to households. As a result, officials consider the current price of water as the starting point and simply raise the price of water from there. In contrast, policy makers can first find out whether or not the current cost of water reflects the household's value of water. They could do so by collecting information and generating estimates of the households' actual value of water. With such information, an informed policy could be implemented in a two-step way. In the first step, the price of water of each household could be increased from its current level to a level that equals their value of water. With this step, the price of water would reflect exactly the true value of water. In the second step, the price of water could then be increased to a point at which users would begin to cut back water use enough to meet the water saving target.

In order to make uninformed and informed policies comparable, we make sure the changes in the average prices of water under the two policy regimes are the same. For example, under the informed policy scenario, when the price of water each household faces is increased from the base level to their value of water, the average price of water increases from 0.24 yuan/m^3 to 0.61 yuan/m^3, which is a 0.37 yuan/m^3 increment (Figure 1, Panel B). Then under the uninformed policy, we increase the price of water each household faces uniformly by a level that is close to 0.37 yuan/m^3 and so the after-change average price is also 0.61 yuan/m^3 as under the informed policy. Similarly, in another change under the informed policy, when the price is first increased to the level of water value and then increased further by 50% of the water value (a two-step procedure), the average price is raised by 0.68 yuan/m^3 and reaches 0.92 yuan/m^3. Then we also raise the price under the uninformed policy by 0.68 yuan/m^3 to 0.92 yuan/m^3 (in one step). Since the average price of water before and after the changes under the informed policy and the uninformed policy are the same, we can put changes in household water use under these two policies on the same graph and plot them against the average water prices.

The simulation results show that the informed policy has the potential to induce sizable water saving. In the first step of the informed policy, which makes sure all households are at the point in which the cost of water is equal to the value of water, households do not change water uses by construction. Once the cost of water has hit the level of water value, however, households are highly responsive to price changes. Suppose policy makers plan to reduce water by 20%.[13] Using the units of the vertical axis of Panel B in Figure 1, this means households need

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[13] In this paper, we will not touch on the issue of the appropriate level of water saving target and leave it for future research.

to reduce their water use to 80% of the base level. In order to meet the 20% water savings target, after the price is increased to 0.61 yuan/m^3 in the first step, the price only needs to be further raised by 10% more (from 0.61 to 0.67) to move households from zero water reduction to 20% water reduction. In order to achieve a 50% water savings target, the price of water only needs to be raised to 0.76 yuan/m^3, only 0.09 yuan/m^3 higher than the level that was needed to hit a 20% target. Therefore, when the price of water reflects the value of water, water pricing policy can be an effective tool in dealing with the water scarcity problem.

Our results also show the price of water needs to be increased greatly. For example, in order to meet a 20% water saving target, the average price is increased to a level close to 0.67 yuan/m^3, leading to a 180% increase in the average price of water. It is important to note, however, that most of the rise in the price of water is in the first step of the informed policy. Of the total rise of price (0.43 yuan/m^3), 87% (0.37 yuan/m^3) is needed just to get all household to the point that the cost of their water is equal to the value of water in production. Such large price rises may be conflicts with other policy goals that aim at keeping food production high and lifting rural incomes. This issue is addressed in later sub-sections.

Comparisons of the informed and uninformed policies indicate that water pricing policy can be implemented more effectively when policy makers recognize that the current cost of water is far below the level of the value of water. For example, if water officials set a water saving target of a 50% reduction in household water use (that is, households reduce water use to 80% of the base level use), under the informed policy, policy makers would increase the price to 0.76 yuan/m^3. However, to achieve a similar saving under the uniformed policy, the price would need to be raised to 0.92 yuan/m^3. This is because under the uninformed policy, policy makers increase the price by an amount that is the same for all of the households, regardless of whether the household has a high or low value for water. Because of the large gaps between the cost of water and the value of water, especially in Xian County and Ci County, if the price were increased only to 0.76 yuan/m^3 (the average water price under the informed policy), it still would be below the true value of water to some of the households. These households would not respond to price changes at all and so the 50% water saving target could not be achieved. As a result, policy makers have to raise the price to 0.92 yuan/m^3 to make sure it exceeds the level of water values of enough number of households so that the water savings reaches the target. Although the change in the average price is same under both policies, the informed policy increases prices in a more targeted way to make sure the water price that each household faces reflects the value of water. Since all households are responsive under the informed policy, the same amount of water price increment is much more effective. In this case, following the uninformed policy would force policy makers to increase the price of water to a higher level than necessary to meet the same water savings targets. This higher price would not only result in higher costs for farmers, but also increase the financial burdens of the water pricing policy if policy makers planned to compensate farmers for their higher costs.

The informed policy, however, does not always out-perform the uninformed policy. When the water saving target is small (e.g., less than a 20% reduction in our case, as marked by the intersection of the informed policy and un-informed policy in the upper left corner of Panel B in Figure 1), the uninformed policy works more effectively in reaching the target. This is because only a small proportion of households need to be responsive in order to reach a small water saving target. Therefore, the uniform increase in water prices under the uninformed policy is sufficient. The uninformed policy works better because it does not require the large increment in water prices to get all household to the point that they are facing their actual water values as is needed in the first step of the informed policy.[14]

Whether an informed policy or an uninformed policy should be pursued depends on the specific water saving target as well as the implementation cost. In general, the cost of implementing an un-informed policy is lower since it does not involve collecting information that is needed to estimate household level water demand. So an uninformed policy is appropriate when the water saving target is small (less than 20% reduction in our case) since the informed policy does not out-perform the un-informed policy. If the water saving target is more than 20% reduction, it is more difficult to make a choice. Raising water prices is more effective under the informed policy. However, the cost of collecting information to estimate the value of water may be high. Policy makers need to determine whether the benefit outweighs the increment in the implementation cost if the informed policy instead of the uninformed policy is used. Although we do not have data on implementation cost, our analysis serves as a starting point in that it provides the benefit of implementing an informed policy.

Impacts of water pricing policy on crop production

Although increasing the price of water has been shown to be effective in reducing water use, when making policies, leaders must also take into account other impacts of higher irrigation costs. We examine how increasing the price of water will affect *crop production* in this sub-section and *producer welfare* in the next sub-section. In the rest of our analysis, we focus only on the informed policy scenario. We run four different simulations. In each simulation, we first raise the price of water each household faces to their value of water, and then increase the price

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[14] When the water saving target is ambitious (e.g., more than 90%), there also is not much difference between the performance of the informed and un-informed pricing policies. This is because a large price increment would be needed to meet such a target under either policy (about 120% of the water value even under the informed policy in our case, Panel B). When the water price is increased greatly, it is likely the price level reaches or exceeds the value of water to most households. Consequently, most households would be responsive under either type of policy, which results in little difference between informed pricing policy and un-informed pricing policy.

of water further by percentages of the level of water values. The price increments in the second step of these four simulations are 10%, 25%, 50% and 100% of the level of water values respectively (Figure 1, Panel B).[15]

Consistent with findings from the descriptive analyses, when the price of water is raised above the level of the value of water, households indeed will adjust their use of water (seen in Figure 1 above) and these changes occurs at both the intensive and extensive margins (Figure 2, Panel A). Importantly, when the price increment is small, most of the adjustments come from intensive margins. For example, when the price of water is increased by 10% after being increased to the level of water value, about 80% of the total reduction in water use comes from adjustments at intensive margins. In the case of wheat, on average, households reduce their water use per hectare from 4,436 to 3,637 m^3.[16] Maize producers also cut back from 2,150 to 1,516 m^3 and cotton producer from 1,653 to 1,244 m^3.

At the same time, households adjust at extensive margins as well. For example, when the price of water is raised by 10%, adjustments in the extensive margin account for 20% of the total adjustments (Figure 2, Panel A). About 3% of the total change comes from shifting from irrigated to non-irrigated agriculture and 17% comes from shifting the crop mix. In our case, the shift in the crop mix mainly comes the shift from maize to cotton, which requires less water relative to maize.

While most of the adjustments occur at the intensive margins when price rises are relatively small, as the price rise gets higher to target higher reductions in water use, more of the

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[15] Under the informed policy, production does not change at all during the first step. As seen in Panel B of Figure 1, water use does not change when the price is raised to each household's value of water. It follows that production also does not change. Because there is no change in water use or crop production, the effect of this step is not graphed in Figure 2.

[16] Water use per hectare in the base run is obtained from simulations. These figures will be slightly different from the observed data in Table 1.

adjustments come from the extensive margins. For example, when the water price is double the level of water value (that is, a 100% increment in the price), almost 75% of the total water reduction comes from adjustments at extensive margins (versus 20% when the price was increased by 10%, Figure 2, Panel A). Most changes at the extensive margin occur when farmers choose to stop irrigating their crops (69%). The remaining 6% comes from changing crop mix. In contrast, only 25% of the fall comes from adjustments at the intensive margins.

Simulations show that adjustments at the intensive and extensive margins affect crop production in two ways. First, stress irrigation reduces the yields of all three crops. For example, when the price increment is 25% of the water value, the average yields of irrigated wheat are reduced by 23.4%, irrigated maize by 11% and irrigated cotton by 4.8%. With lower yields, the level of crop production is, of course, lower for all crops, ceteris paribus. Yield changes due to adjustments at the intensive margin, however, is only part of the reason why grain production changes. Adjustments at the extensive margins shift crop production from grain to non-grain crops. Grain area (the sown area of wheat and maize) is reduced by 4.3% with a 25% increase in water prices. Farmers also switch from irrigated area to non-irrigated area. The total irrigated area of all crops falls by 15.6%. Hence, in total when the price of water is raised by 25%, grain production falls by 14.3%, of which 3.5 percentage points came from changes at the extensive margin.

When accounting for both the both lower yields and smaller acreage that arise from rising water costs, the simulation results imply that a wide-ranging, pan-provincial water pricing policy would reduce food production in China significantly. In particular, the production of wheat is most affected. Since the growing season of maize and cotton in Hebei province coincides with the rainy season while that of wheat does not, wheat production relies more on irrigation and falls more when the cost of irrigation rises. For example, when the price of water is doubled, wheat production is reduced by 45% (Figure 2, Panel B). Since Hebei province produces about 12% of China's wheat output, if the informed water policy were implemented only in Hebei, the fall in wheat output would be equivalent to more than 5% reduction in China's total production of wheat. Furthermore, as policy makers choose to raise water prices higher, the amount of crop production reduction that is due to adjustments at the extensive margin is greater. For example, when the price of water is doubled, of the 45% reduction in wheat output, 32.4 percentage points (or 72% of the total reduction) comes from adjustments at the extensive margin.

Welfare impacts of water pricing policy

The impact of higher irrigation costs is not limited to crop production. Incomes of rural households are also lower if the water pricing policy is implemented (Figure 3, Panel A). In the first step of each simulation, since the real price of water each household face (as measured by the value of water) did not change, households do not change their water uses or crop production. Incomes are reduced since the actual cost of water rises and the negative effect on income of pricing policy is solely attributed to higher water prices. As can be seen from moving from bar 1 to bar 2 in Panel A, on average, crop income drops by 268 yuan per household.

When irrigation costs are increased during step 2, although income continued to decline due to higher water price, the rate of decline slows. For example when policy makers increase the price of water by 10% (after the initial increment in the first step), on average, crop income decreases from 1,938 yuan to 1,634 yuan (Figure 3, Panel A). A 10% increase in the water price only drops crop income further by 30 yuan. This is because farmers are responsive to changes in water price since it reflects the value of water to them. Since farmers respond to increase in water price by reducing levels of water use, the impact on crop income is smaller than that in the initial step. Crop income drops from 1,938 to 1,518 yuan when the price of water is doubled.[17]

Hence, while water policy has great potential in saving water, the impact of water pricing policy on producer income poses a major challenge to China's policy makers in today's political economy environment. China has made remarkable progress in alleviating poverty in its rural areas in the past and the leaders are definitely intent on continuing to alleviate poverty in rural China (Rozelle, Zhang and Huang, 2003). The government has set the target of lifting 23.65 million people out of poverty in the next five years (Xinhua News Agency, 2006). A set of tax reform policies that targets at eventual elimination of taxation on rural households has been implemented over the past decades (Brandt, Rozelle and Zhang, 2005). With such a policy environment, there will be strong resistance against any policy that results in lower rural incomes. Almost certainly, if any water policy were to be implemented in rural China, complementary policies would be needed to offset the impacts of higher irrigation costs on rural income.

Since rural households shoulder the burden of conserving water, they should be compensated with at least the amount of their incomes losses. One solution is to develop a subsidy program in tandem with the water pricing policy that would provide households with income transfers to offset the reduction in income from water pricing policies. Our results, however, show that such a policy would have to rely on new fiscal transfers, especially as the price of water was raised to higher levels. Suppose the price of water is raised through imposing a tax on per unit of water use. When the price of water is raised from its initial actual cost to the level of the household's value of water, most of the amount needed to fund the transfer program (administrative costs aside) can come from the program (the tax revenue collected). However, as the level of the water tax increases, the deadweight loss associated with the tax becomes larger.

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[17] It should be noted that in our analysis that we do not consider any general equilibrium effects. If water pricing policies were implemented over large areas of China, and millions of farmers changed their crop mix, the price of grain crops might rise. If this effect were considered, the income impact of higher irrigation costs would be lower.

Our results show this clearly. If households are compensated with the rebate of the collected tax revenue, the reduction in household crop income is smaller.[18] However, the tax rebate is not enough to compensate completely for the loss in crop income.[19] For example, with a 25% increase in the irrigation cost, on average, each household loses 343 yuan of their crop income on average while only 187 yuan per household is collected as tax (Figure 3, Panel A). There is a 156-yuan gap (or 8% of the base level crop income) between the income loss and the tax revenue collected. The level of the gap increases with the level of increment in the irrigation cost. When irrigation cost is doubled, the crop income loss (420 yuan) is more than six times the level of tax revenue (65 yuan). To compensate for these gaps, outside funding must be provided.

Despite its significant negative effects on average income, our simulation results show that water pricing policy does not deteriorate the distribution of income. For example, doubling irrigation cost only increases the Gini coefficient of household total income from 0.3881 to 0.391, which is only a 0.7% increase (Figure 3, Panel B). This is consistent with findings in Dinar and Tsur (1995). In our case, one important reason for this small impact is that in rural China land is equally allocated to households both in terms of land size and soil quality.

Conclusions

Tackling the growing water scarcity problem has become one of the most important tasks that face China's leaders. Past water policies, including the policies that increase water supplies

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[18] If the tax rebates households receive equal the amount of taxes they paid, it may undermine their incentives to reduce water use had households known beforehand the compensation mechanism. Hence, the rebate is given to each household in the form of a share of the total tax revenue collected in the village. The share is the proportion of the household land holding in the total cultivated area of the village. Returning the tax revenue based upon the land size makes the amount of rebate independent of the amount of water used. Meanwhile, since the level of water use is correlated with the size of land, the amount of rebate each household receive is correlated with the amount of tax they paid.

[19] In the first step when the water price is increased to the level of water value, the input uses and level of output are not affected. The reduction in crop income is exactly the increase in water cost. Hence if the tax revenue is returned to households, crop income is not changed.

alone and those that promote the adoption of water saving technologies, have not been effective. Relying on a set of household level data, this paper examined the potential for conserving water through water pricing reform. We also examined the impacts on production and producer welfare.

Our results show that the current cost of water is far below the true value of water in many of our sample areas. Since water is severely under priced, water users are not likely to respond to small increases in water prices. Therefore, one of our main findings is that a necessary step in establishing an effective water pricing policy is to increasing the price of water up to a point that it equals the value that the water has to the household. Increases in water prices once they are set at the value of water can lead to significant water savings. In short, unlike past water policies, our study show that water pricing policy, by directly giving users incentives, has the potential of resolving the water scarcity problem in China.

Our analysis also shows that higher water prices affect other aspects of the rural economy. Higher irrigation costs will lower the production of all crops, in general, and that of grain crops, in particular. This may hurt the nation's food security goal of achieving 95% self-sufficiency for all major grains in the short run. Furthermore, when facing higher irrigation costs, households suffer income losses, although income distribution does not deteriorate. As a result, it is imperative that complementary policies should be used to offset these negative impacts. For example, a comprehensive set of subsidy policies are also needed to offset the loss in income. To be effective in reducing water, of course, subsidies must be decoupled from production decisions.

Our paper provides both good news and bad news to policy makers. On the one hand, water pricing policies have great potential for curbing demand and helping policy makers address the emerging water crisis. Irrigation is central for China to maintain food security in the long run and will continue to be one investment that enables China to lift its future production of food and meet its food grain security goals (Huang, Rozelle and Rosegrant, 1999). The goal of water pricing policy, which is to manage water resources in a sustainable way, does not conflict the long run goal of the nation's food security policy. On the other hand, dealing with the negative production and income impacts of higher irrigation cost will pose a number of challenges to policy makers, at least in the short run. If China's leaders plan to increase water prices to address the nation's water crisis, an integrated package of policies will be needed to achieve water savings without hurting rural incomes or national food security.

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Table 1. The cost of water, depth to water and water use in Hebei Province, China 2004.

Percentile of the cost of water		(1) Depth to water (m)	(2) Average cost of water (yuan/m^3)	(3) Volume of water use per unit of land (m^3/ ha)
			Wheat	
1	Average	38.4	0.24	4,455
2	0-25%	15.9	0.07	5,321
3	26-50%	19.4	0.16	4,956
4	51-75%	51.9	0.26	4,628
5	76-100%	69.0	0.50	2,276
			Maize	
6	Average	44.7	0.24	2,022
7	0-25%	15.0	0.05	2,640
8	26-50%	35.4	0.15	2,534
9	51-75%	62.2	0.24	1,730
10	76-100%	65.3	0.51	1,184
			Cotton	
11	Average	59.1	0.29	1,477
12	0-25%	41.3	0.14	2,322
13	26-50%	45.7	0.23	1,950
14	51-75%	47.3	0.34	1,394
15	76-100%	108.0	0.51	978

Data source: Authors' survey in 2004 (CWIM data).

Table 2. The depth to water and crop mix in Hebei Province, China, 2004

Percentile of the depth to water	(1) Average depth to water (m)	(2) Percentage of rainfed sown area (%)	(3) Average share of household sown area that cultivates non-grain crop [a] (%)
0-25%	6	12	15
26-50%	21	15	25
51-75%	58	28	33
76-100%	91	37	31

Data source: Authors' survey in 2004 (CWIM data).

[a] Non-grain crops include cotton, vegetables, fruits, trees, peanuts.

Table 3. Number of sample households that grew Wheat, Maize or Cotton, Hebei Province, China, 2004

		(1) Total number of households	(2) Number of households that grew wheat	(3) Number of households that grew maize	(4) Number of households that grew cotton
1	Total	88	63	86	18
2	Xian County	30	26	28	8
3	Tang County	29	19	29	1
4	Ci County	29	18	29	9

Data source: Authors' survey in 2004 (CWIM data).

Table 4. Estimation results of the Wheat production frontier, $\sum_i \alpha_i x_i - \sum_i \sum_{i'} x_i z_{ii'} x_{i'}$

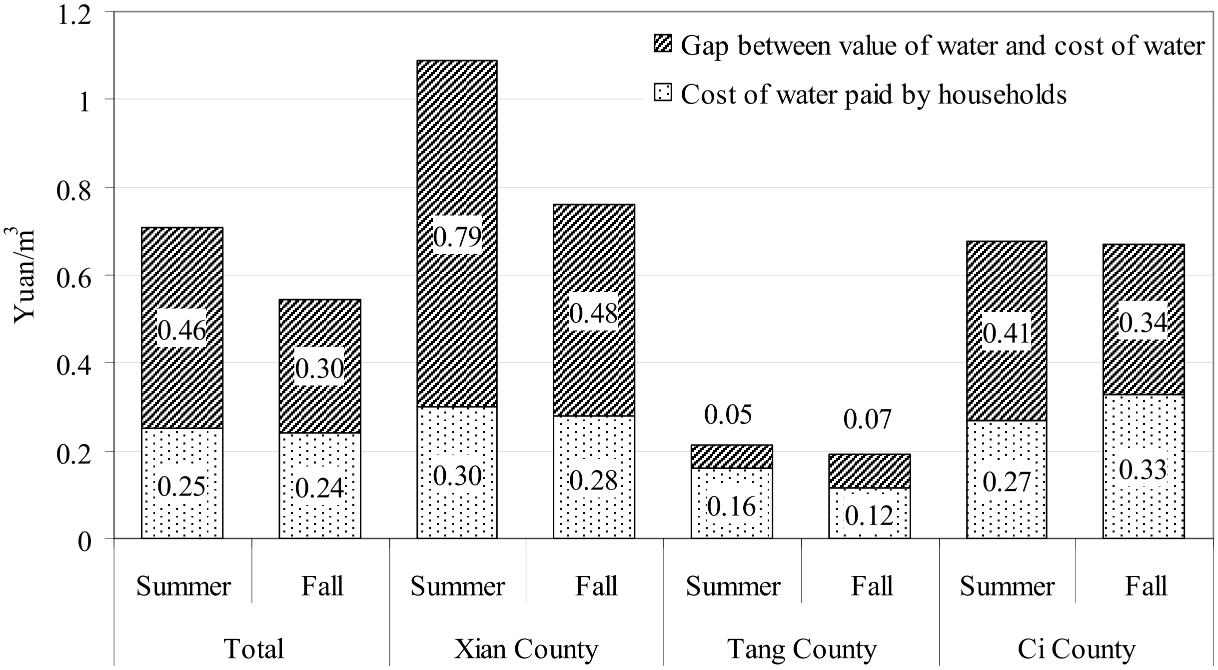
County	Input	α_i	$z_{ii'}$				
			Land	Water	Labor	Fertilizer	Capital
Xian County	Land	34.7379 (6.424)**	66.3825 (19.311)**				
	Water	1.7589 (0.136)**	-0.2111 0.074	0.0012 (0.000)**			
	Labor	0.9125 (0.330)**	-0.1297 0.198	0.0005 (0.00027)*	0.0039 (0.002)*		
	Fertilizer	1.3989 (0.411)**	-0.1046 0.151	-0.0004 0.001	-0.0001 -0.001	0.0028 (0.002)*	
	Capital	1.3232 (0.520)**	-0.2267 0.276	0 0.001	-0.0027 (0.0015)*	-0.0012 0.002	0.0101 (0.007)*
Tang County	Land	184.3451 (46.532)**	378.1395 (183.741)**				
	Water	0.4622 (0.100)**	-0.4763 0.355	0.0016 (0.001)**			
	Labor	0.9488 (0.218)**	-0.7962 0.615	0.0025 (0.001)**	0.009 (0.003)**		
	Fertilizer	0.5001 (0.134)**	0.0452 0.477	-0.0021 0.001	-0.0033 -0.002	0.0063 (0.003)**	
	Capital	1.571 (0.243)**	-1.7664 1.367	0.0008 0.003	-0.0037 (0.0021)*	-0.0045 0.005	0.0402 (0.020)**
Ci County	Land	48.7264 (12.906)**	80.1194 (44.890)**				
	Water	2.0536 (0.169)**	-0.0748 0.129	0.0018 (0.001)**			
	Labor	0.6073 (0.136)**	-0.2187 0.281	0.0006 (0.000)*	0.0038 (0.002)*		
	Fertilizer	0.2492 (0.076)**	0.0085 0.197	-0.0012 0	-0.0013 0.001	0.003 (0.001)**	
	Capital	0.703 (0.293)**	-0.5294 0.504	-0.0014 0.002	-0.0005 0.003	-0.0023 0.002	0.0174 (0.010)**

a. For the sake of brevity, estimation results of the production frontier of maize and cotton as well as the set of technical inefficiency parameters are not reported here.

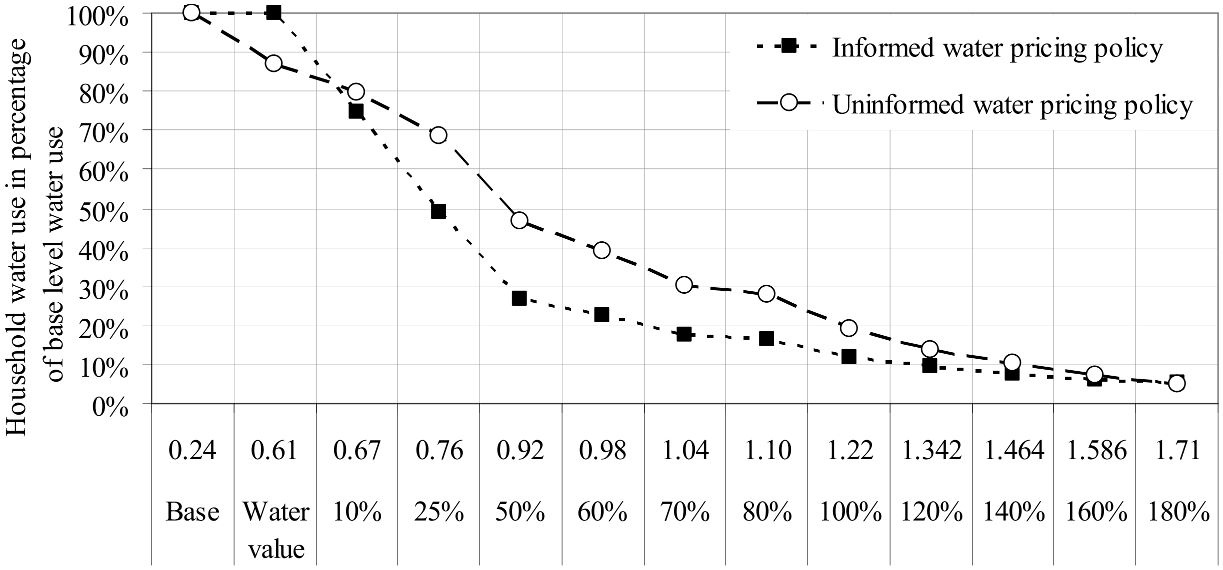
b. Bootstrapped standard errors are reported in parentheses.

c. When performing the GME estimation, we change the unit of land to be squared meter so that the magnitude of land is in range with that of other inputs. Because of the rescaling, coefficients on land are large in magnitudes.

d. Asterisk (*), double asterisk (**) and triple asterisk (***) denote coefficients significant at 10%, 5% and 1% levels respectively .



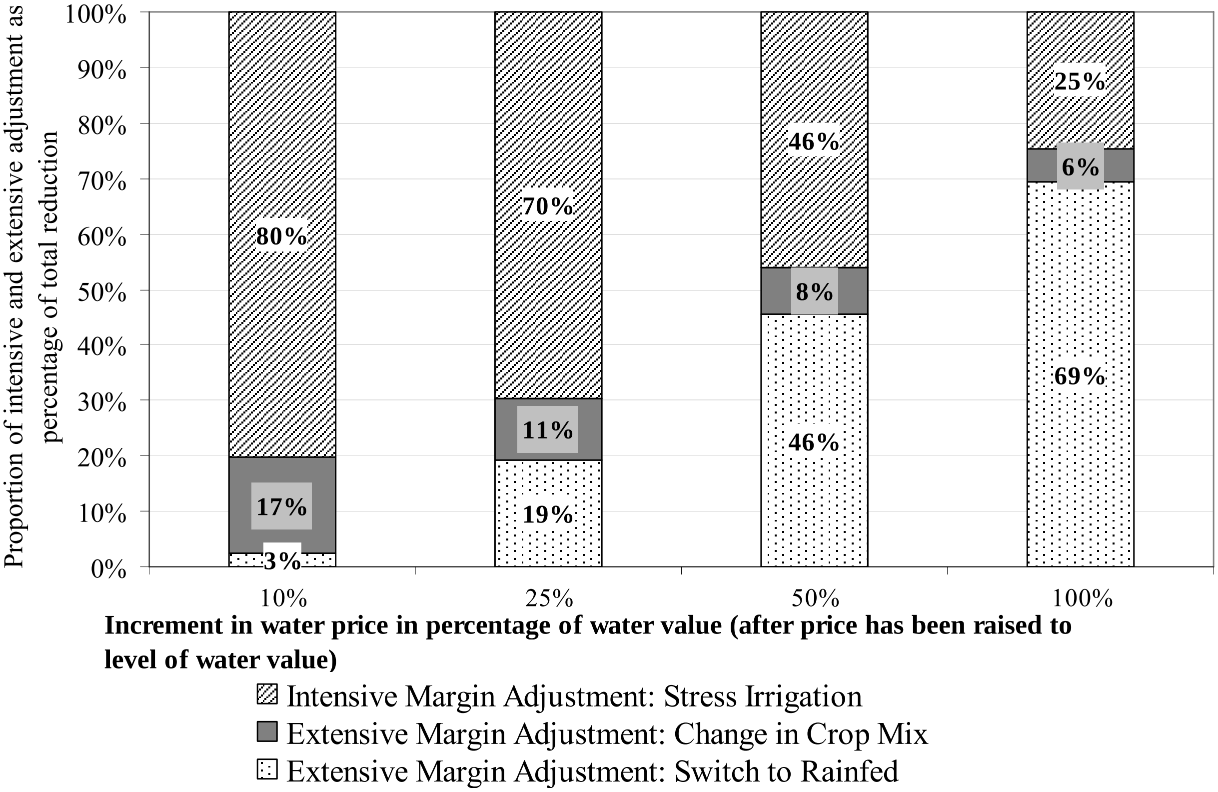
Panel A. Value of water and cost of water (*Yuan/m*^{3})



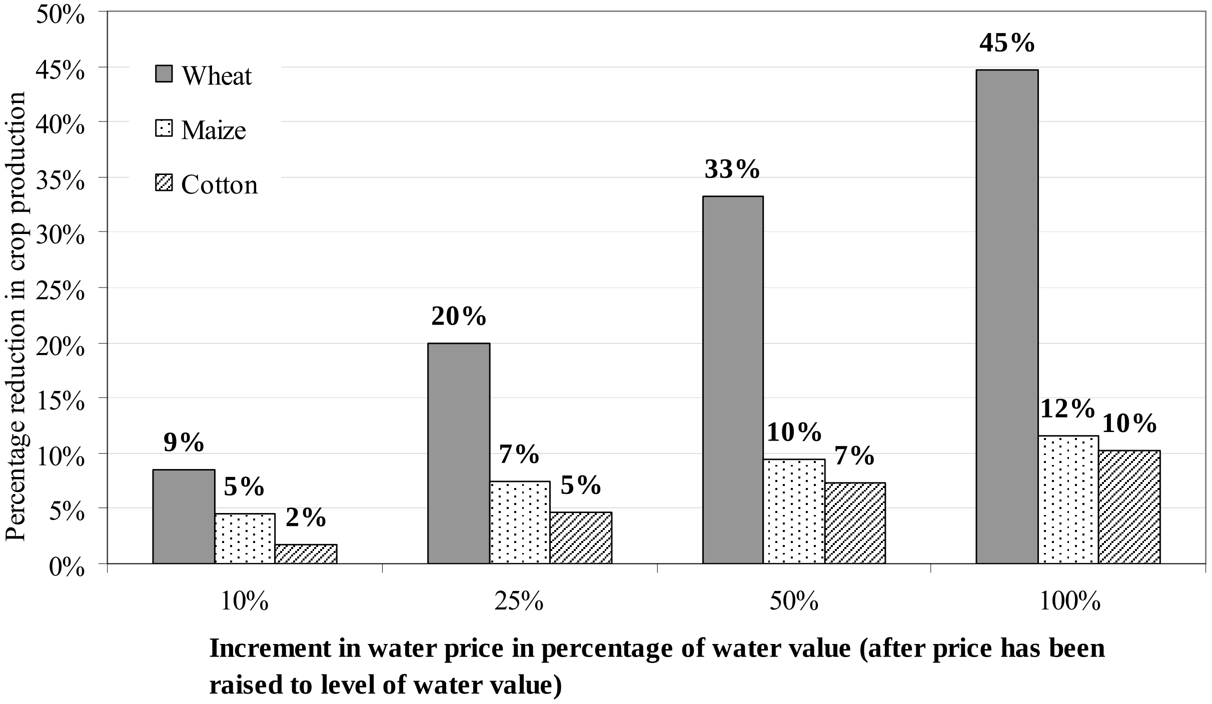
Upper x axis: Average price of water (yuan/m^3)
Lower x axis: Increment in water price in percentage of water value

Panel B. Comparison of informed and uninformed water pricing policy

Figure 1. Effects of higher water prices on household water use

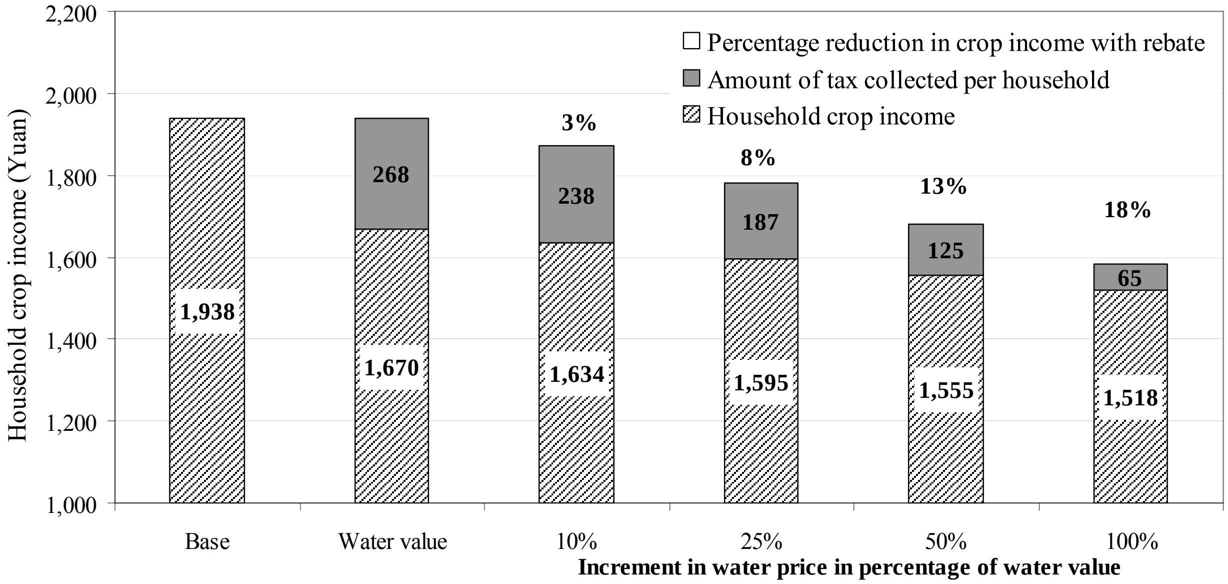


Panel A. Composition of water use adjustments in response to higher water prices

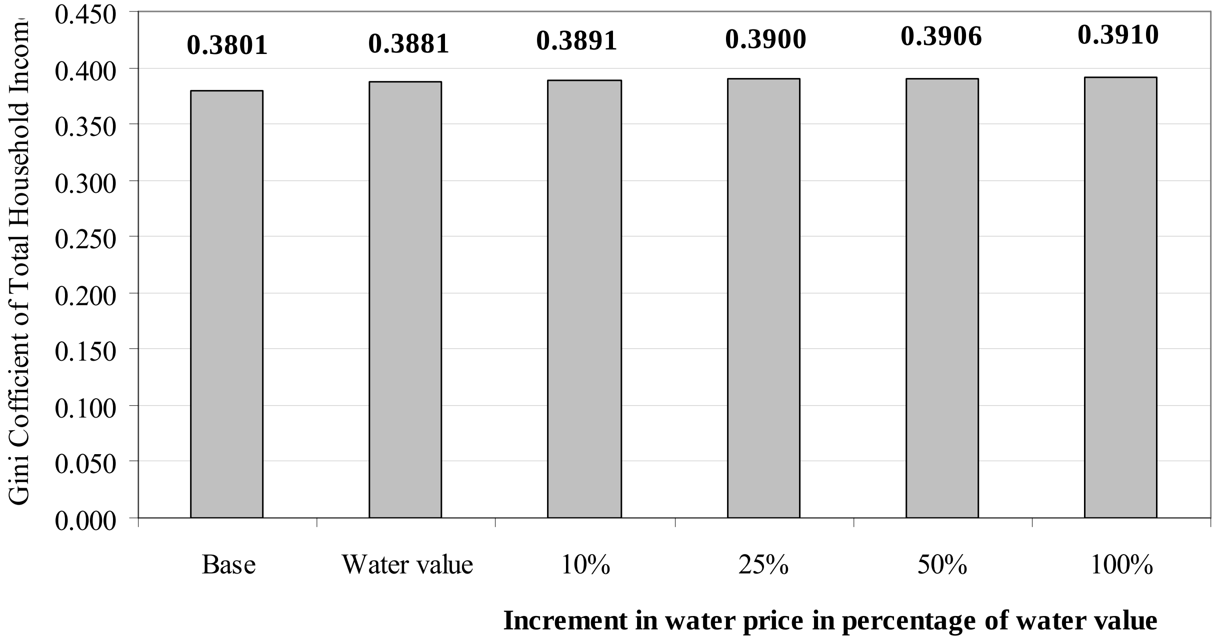


Panel B. Crop production reduction in response to higher water prices

Figure 2. Effects of higher water prices on crop production under informed water pricing policy



Panel A: Effects of higher water prices on household crop income



Panel B. Effects of higher water prices on distribution of household total income

Figure 3. Effects of higher water prices on produce welfare under informed water pricing policy